Table B.4.6 FLOW DURATION AT MANAMPITIYA

Year	Maximum (m3/s)	95th days (m3/s)	185th days (m3/s)	275th days (m3/s)	355th days (m3/s)	Minimum (m3/s)	Remarks
1954	1511	295	165	107	81	75	
1955	1141	327	222	153	75	63	
1956	1450	175	118	83	48	41	
1957	3273	309	148	85	53	47	
1958	1869	293	172	104	54	49	
1959	1259	251	131	88	38	29	
1960	1676	305	190	127	84	59	
1961	1567	214	135	100	65	59	
1962	1179	253	158	102	69	57	
1963	1862	272	149	104	70	62	
1964	1742	231	145	100	53	43	
1965	1910	286	166	106	70	64	
1966	1372	257	142	82	55	49	
1967	1822	254	150	96	62	58	
1968	1114	230	150	92	57	49	
1969	1480	196	126	83	47	40	
1970	1423	253	139	96	60	40	
1971	1472	259	149	109	59	51	
1972	1507	275	127	69	36	27	
1973	1547	150	92	58	36	31	
1974	1425	190	127	87	40	29	
1975	1095	239	146	91	46	39	
1976	1360	132	50	23	13	11	
1977	1418	164	69	39	21	16	
1978	1815	230	101	53	26	19	
1979	1133	193	65	21	10	7	
1980	641	84	35	17	9	7	
1981	1269	98	46	28	12	9	
1982	1461	98	39	17	8	6	
1983	-	-	-	-	-	-	Insufficient data
1984	1328	228	98	24	5	3	
1985	1009	172	100	53	25	19	
1986	1580	166	72	36	13	12	
1987	915	162	80	29	10	6	
Average-:	1577	251	148	96	57	48	Period : 1954-1975
Average-:	1474	219	121	75	43	36	Period : 1954-1987
Average-:	1266	157	69	31	14	10	Period : 1976-1987

Remarks: Catchment Area : 7418 Sq.Km

Table B.5.1 ANNUAL MAXIMUM FLOOD RECORDS AT SELECTED STATIONS

Hydro-logical Year	Maha Oya at Maha Oya		Uma Oya at Welimada		Kalu Ganga at Pallegama		Mi Oya at Mahauswewa	
	Date	Value (m3/s)	Date	Value (m3/s)	Date	Value (m3/s)	Date	Value (m3/s)
1940	-	-	-	-	-	-	-	-
1941	-	-	-	-	-	-	-	-
1942	-	-	-	-	-	-	-	-
1943	-	-	-	-	-	-	-	-
1944	-	-	-	-	-	-	-	-
1945	-	-	-	-	-	-	-	-
1946	12.01.1947	269	-	-	-	-	-	-
1947	30.01.1948	257	-	-	-	-	-	-
1948	12.01.1949	566	-	-	-	-	-	-
1949	08.12.1949	402	-	-	-	-	-	-
1950	18.01.1951	326	-	-	-	-	-	-
1951	31.12.1951	204	-	-	-	-	-	-
1952	23.01.1953	245	-	-	-	-	-	-
1953	23.01.1954	195	-	-	-	-	11.01.1954	87
1954	08.12.1954	159	-	-	-	-	09.12.1954	74
1955	11.01.1956	151	-	-	-	-	01.12.1955	117
1956	18.02.1957	328	-	-	-	-	21.04.1957	108
1957	-	-	25.12.1957	33	-	-	13.12.1957	135
1958	-	-	21.06.1959	107	-	-	25.12.1958	36
1959	-	-	28.09.1960	55	-	-	23.10.1959	62
1960	-	-	12.08.1961	41	15.01.1961	606	11.11.1960	187
1961	-	-	08.09.1962	38	03.02.1962	255	02.11.1961	173
1962	-	-	-		06.01.1963	470	08.01.1963	286
1963	-	-	15.09.1964	85	20.02.1964	311	19.11.1963	169
1964	-	-	16.08.1965	57	13.02.1965	399	08.05.1965	81
1965	-	-	25.09.1966	59	23.01.1966	101	11.12.1965	200
1966	-	-	24.06.1967	34	05.02.1967	436	10.11.1966	227
1967	-	-	05.05.1968	92	06.12.1967	283	22.10.1967	370
1968	-	-	02.06.1969	58	21.01.1969	278	20.11.1968	172
1969	-	-	05.08.1970	85	28.12.1969	453	05.04.1970	59
1970	-	-	22.09.1970	100	12.12.1970	425	28.11.1970	38
1971	-	-	16.07.1972	99	18.12.1971	186	14.05.1972	76
1972	-	-	23.06.1973	41	-	-	10.11.1972	67
1973	-	-	27.07.1974	238	-	-	28.12.1973	49
1974	-	-	25.09.1975	41	-	-	26.05.1975	13
1975	-	-	25.09.1976	41	-	-	03.04.1976	60
1976	-	-	-	-	-	-	02.12.1976	73
1977	-	-	-	-	-	-	16.11.1977	199
1978	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	26.09.1980	116
1980	-	-	-	-	-	-	14.10.1980	139
1981	-	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	04.12.1982	11
1983	-	-	-	-	-	-	08.03.1984	365

Table B.5.2 PEAK FLOOD DISCHRAGE AT SELECTED STATIONS

No.	Reservoir	Catchment Area (Sq.km)	T=1/20 Flood Discharge (m3/s)	T=1/50 Flood Discharge (m3/s)	T=1/100 Flood Discharge (m3/s)	T=1/200 Flood Discharge (m3/s)	T=1/1000 Flood Discharge (m3/s)
1	Periya Aru	119	479	573	644	714	877
2	Nilobe	159	241	282	313	344	415
3	Maha Oya	300	498	582	645	708	853
4	Elahera	774	1059	1274	1436	1597	1970
5	Morape	555	1519	1880	2151	2420	3045
6	Kandaketiya	387	376	441	489	537	649
7	Watawela	65	175	212	240	268	332
8	Talawakelle	297	1122	1384	1573	1762	2198
9	Talawakanda	520	651	818	943	1067	1356
10	Holbrook	121	223	272	308	345	429
11	Welimada	179	447	556	638	720	908
12	Pallegama	194	600	697	770	843	1011
13	Horowpotana	942	1280	1665	1953	2240	2906
14	Parasan Kulam	133	263	320	362	404	502
15	Kapachchi	2117	1818	2352	2753	3151	4075
16	Mahauswewa	595	283	344	390	436	542

Table B.5.3 VALUES OF QP, TP AND TB FOR UNIT HYDROGRAPH AT PROPOSED DAM SITES

No.	Proposed	Catchment Area (Sq.km)	Qp (m3/s)	Tp (hr)	Tb (hr)
1	Watawala	69	56.7	4	30
2	Ulapane	782	428.5	6	36
3	Sudu Ganga	305	200.6	5	33
4	Badulu Oya	267	219.5	4	30
5	kalu Ganga	204	167.7	4	30
6	Mahatotila Oya	168	276.2	2	24
7	Lower Uma Oya	521	571.0	3	27
8	Malwatu Oya	2113	837.6	15	62
9	Kapirigama	34	40.4	5	33
10	Parangi Aru	427	230.8	11	51
11	Pali Aru	91	77.3	7	39
12	Kanagarayan Aru	85	56.2	9	45
13	Kitulagala Oya	104	88.3	7	39
14	Mukunuwewa	142	93.8	9	45
15	Yan Oya	1320	523.3	15	62
16	Horowupotana	950	403.5	14	59
17	Gallodai Aru	95	80.7	7	39
18	Maha Oya	230	152.0	9	45
19	Rambukkan Oya	140	69.4	12	54
20	Magalawatawan	115	85.5	8	42
21	Tammannewa	64	76.1	5	33

Remarks: Qp : Peak discharge of unit hydrograph in m3/s
Tp : Unit hydrograph time to peak in hours
Tb : The time base of unit hydrograph in hours

Table B.5.4 PEAK FLOOD DISCHARGE AT PROPOSED DAM SITES

No.	Reservoir	Catchment Area (Sq.km)	T=1/20 Flood Discharge (m3/s)	T=1/50 Flood Discharge (m3/s)	T=1/100 Flood Discharge (m3/s)	T=1/200 Flood Discharge (m3/s)	T=1/1000 Flood Discharge (m3/s)
1	Watawala	69	470	550	620	680	820
2	Ulapane	782	3700	4360	4850	5350	6510
3	Sudu Ganga	305	1190	1380	1520	1660	2000
4	Badulu Oya	267	840	990	1090	1200	1450
5	Kalu Ganga	204	1140	1350	1500	1650	2010
6	Mahatotila Oya	168	1010	1180	1310	1430	1730
7	Lower Uma Oya	521	2140	2510	2770	3040	3670
8	Malwatu Oya	2113	4700	5660	6320	6990	8430
9	Kapirigama	34	280	340	370	410	500
10	Parangi Aru	427	1280	1540	1720	1900	2290
11	Pali Aru	91	430	510	570	620	750
12	Kanagarayan Aru	85	420	490	550	610	740
13	Kitulgala Oya	104	640	750	840	920	1130
14	Mukunuwewa	142	690	820	920	1010	1240
15	Yan Oya	1320	4060	4840	5400	5960	7340
16	Horowupotana	950	3120	3710	4140	4570	5620
17	Gallodai Aru	95	580	690	770	840	1030
18	Maha Oya	230	1120	1330	1480	1630	2000
19	Rambukkan Oya	140	530	630	700	780	950
20	Magalawatawan	115	620	740	820	910	1110
21	Tammannewa	64	410	490	550	600	720

FIGURES

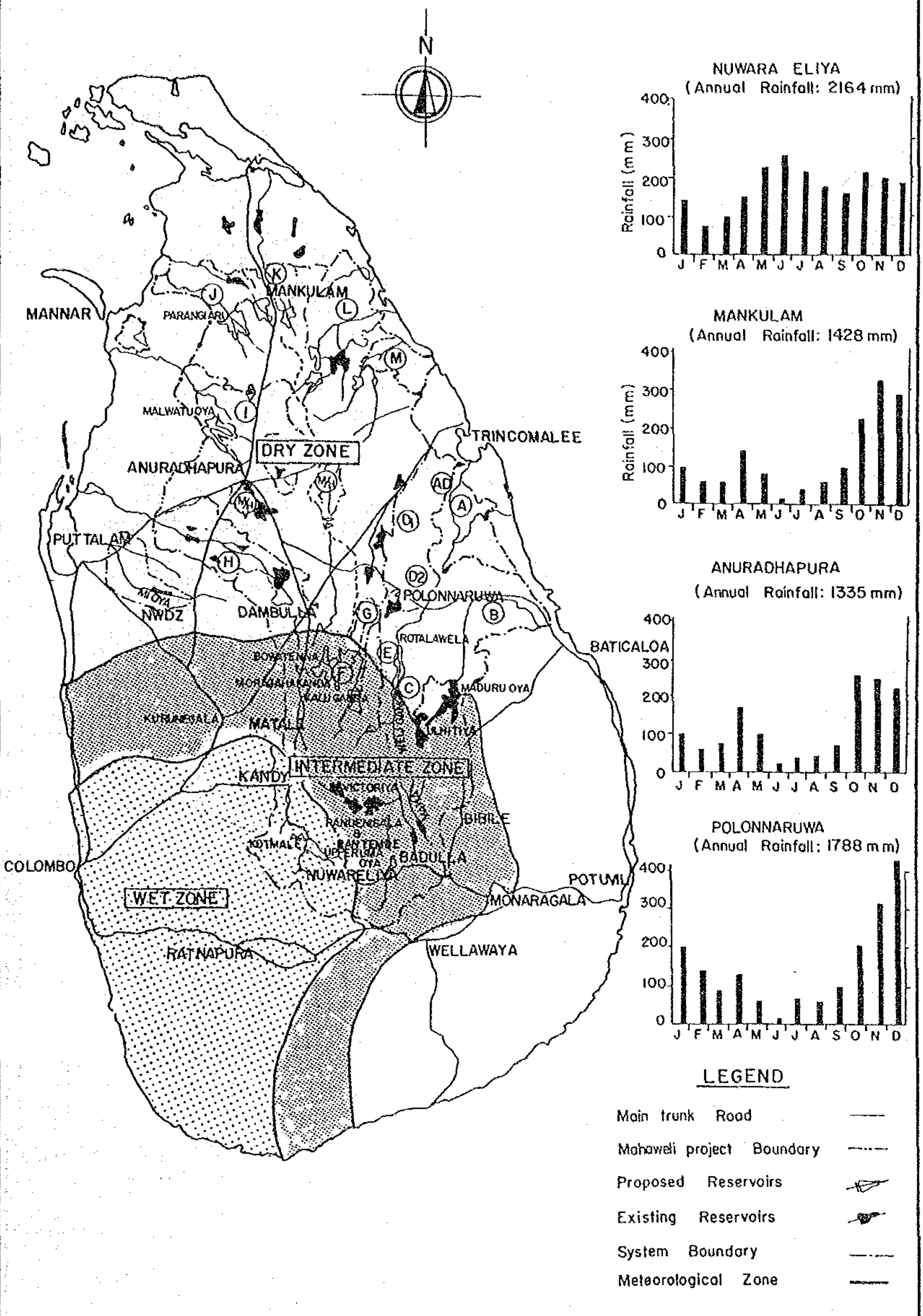

Fig. B.2-1 Meteorological Zone in Sri Lanka and Average Monthly Rainfall in the Study Area

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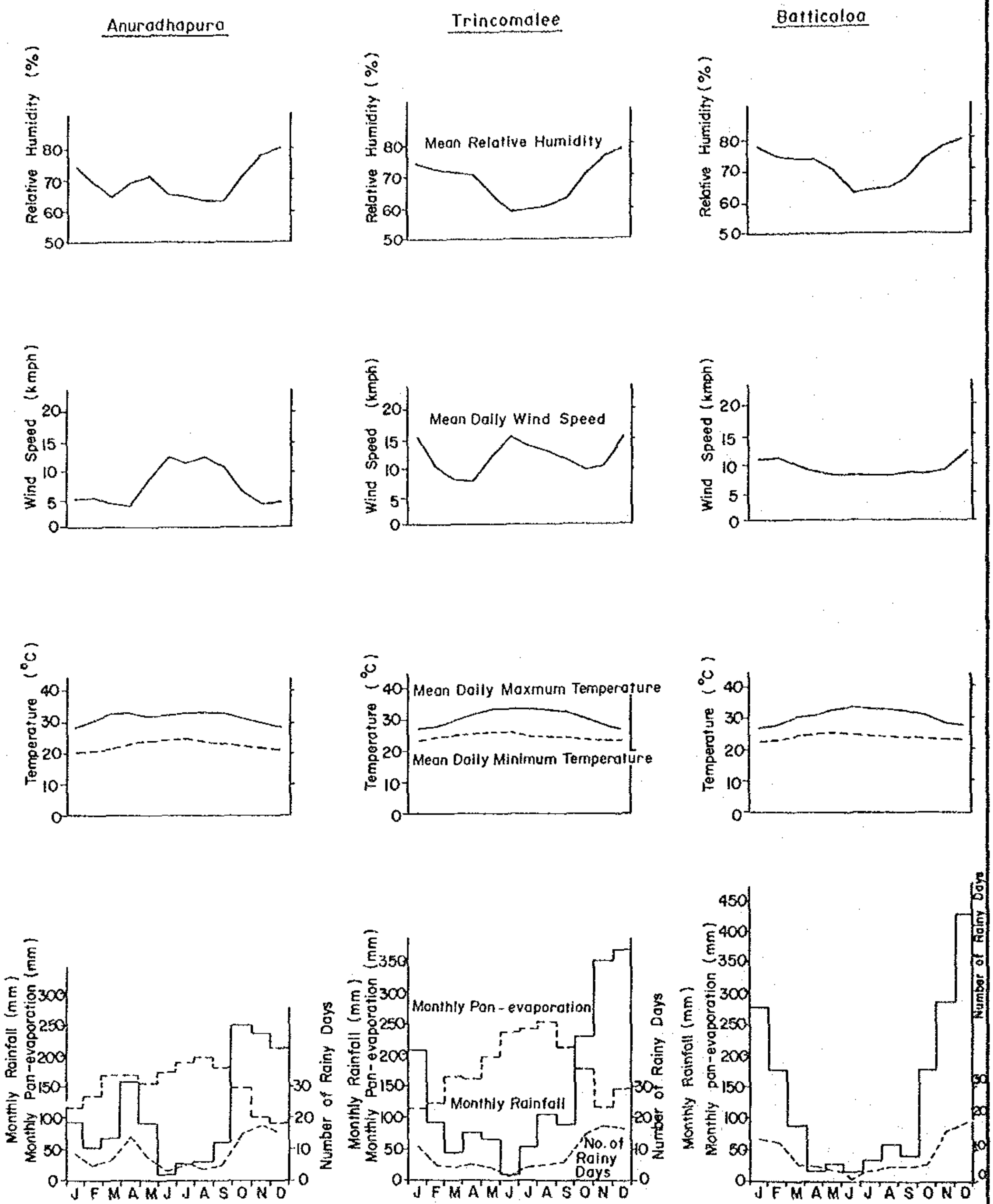

Anuradhapura		Trincomalee		Batticaloa	
Annual Rainfall	: 1335mm	Annual Rainfall	: 1728mm	Annual Rainfall	: 1655mm
Annual No. of Rainy Days:	112 days	Annual No. of Rainy Days :	105 days	Annual No. of Rainy Days	: 107 days
Annual Pan-evaporation :	1864 mm ∠1	Annual Pan-evaporation :	2184 mm ∠2	Annual Pan-evaporation:	NA ∠3

Remarks: ∠1 Data at Maha Illuppallama
∠2 Data at Kantalai
∠3 No data available

Fig. B.2-2 Mean Annual Climatological Pattern in the Study Area

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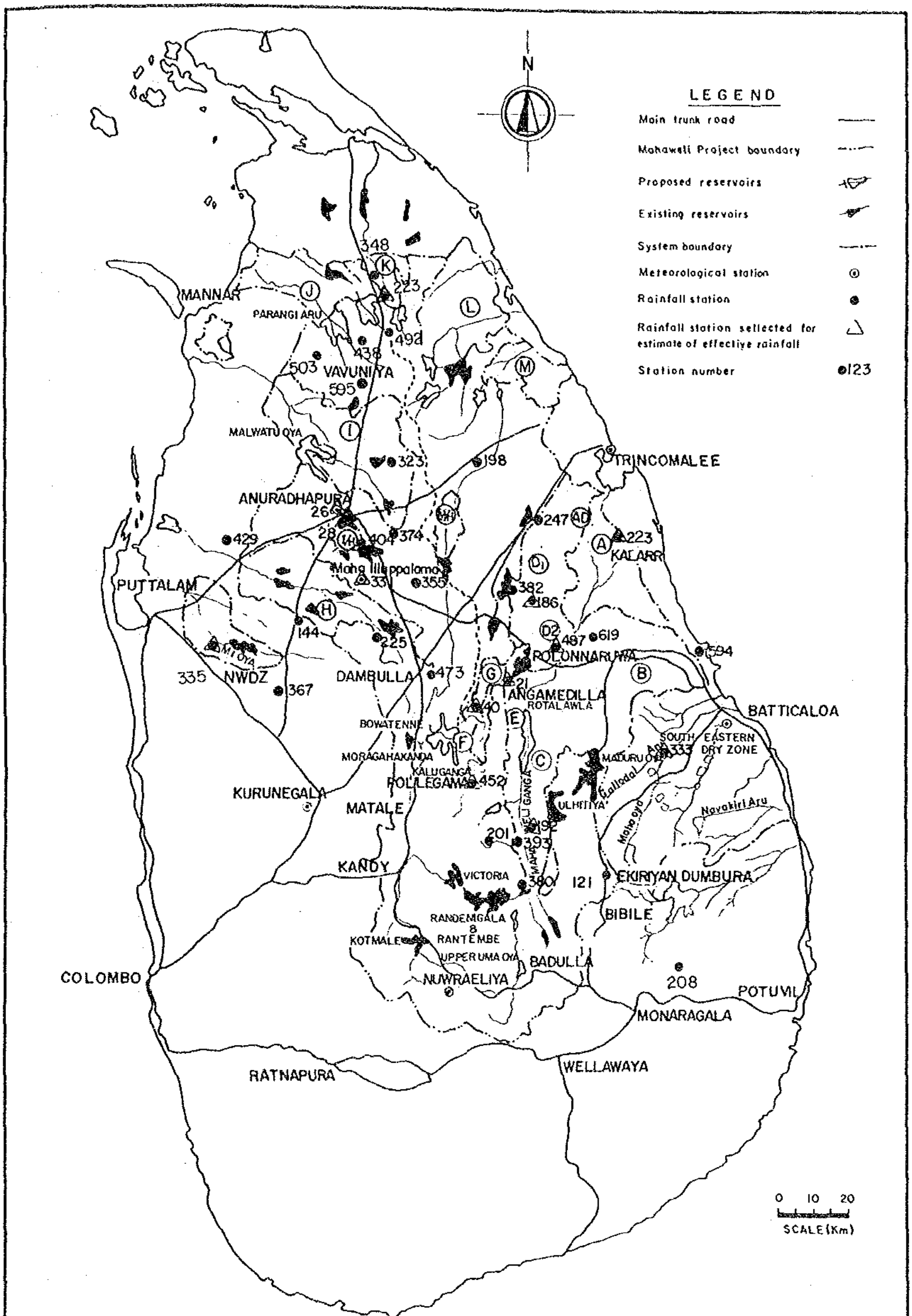

Fig. B.2-3 Meteorological and Rainfall Stations

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Rainfall Data

STATION	ST. No.		1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Angamedilla	21	1940																				
Anuradhapura	26	1940																				
Bakamuna (Elahera)	40	1940																				
Ekiviyandukburo	121	1940																				
Galgamuwa Tank	144	1940																				
Hingurakgoda	186	1940																				
Horaborawewa	192	1940																				
Horowupotana	198	1940																				
Iddemekelle Estate	201	1940																				
Inginiyagala	208	1940																				
Kal - Aar	223	1940																				Sep
Kalawewa	225	1949																				Feb
Kanakarayan-kulam	233	1940																				Aug
Kantalai Tank	247	1949																			Jun	
Kebetegollawa	261	1940																				
Medawachchiya	323	1940																				
Maha Illuppallama M	331	1962																				
Maha Oya	333	1940																				
Mahouswewa	335	1940																				Sep
Mankulam	348	1940																				
Moradankadawela	355	1940																				
Mediyawa	367	1940																				
Mihintale	374	1940																				
Minipe - Irrigation	380	1940																				
Minneriya - Tank	382	1940																				
Morayaya	393	1940																				
Nachchaduwa	404	1940																				
Nochchiyagama	429	1949																				
Omatai	438	1957																				
Pallegama	452	1940																				
Pelwehera	473	1940																				
Polonnaruwa Agr	487	1949								Aug												
Puliyankulam	492	1947																				
Puwaeasau-Kulam	503	1940					Apr															
Varaichenai	594	1949																				Sep
Vavuniya Agr	595	1940																				
Welikanda	619	1949						Jun														

Stream Flow Data

STATION	RIVER	CATCHMENT AREA (Sq.km)		1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Talawakelle	Kotmale Oya	315	1954																Jul	
Morape	Kotmale Oya	555	1949																	
Peradeniya	Mahaweli Ganga	1167	1949																Nov	
Randenigala	Mahaweli Ganga	2365	1954														May			
Rantembe	Mahaweli Ganga	3113										Jun							Apr	
Weragantota	Mahaweli Ganga	4092	1945																Sep	
Manampitiya	Mahaweli Ganga	7418	1953																Jul	
Elahera	Amban Ganga	774	1946																May	
Angamedilla	Amban Ganga	1363																Mar		
Pallegama	Kalu Ganga	194	1960			Feb														
Mahouswewa	Mi Oya	595	1959															Jul		
Maduru Oya bridge	Madur Oya	158												Sep			Oct			
Kappachchi	Malwathu Oya	2117	1949															Sep		
Horowupotana	Yan Oya	942	1951																	
Yakawewa	Mukunu Oya	111										Nov								
Chinnavalayan kaddu	Parangi Aru	560																Feb		
Parasan kulam	Kanagrayan Aru	133																Sep		
Nilabe	Rambukkan Oya	159	1951																	
Pallebedda	Ranbukkan Oya	137											Oct							
Veragoda	Gallodai Aru	225	1949																	

Fig. B.3-1 Available Rainfall Data and Stream Flow Data in the Study Area

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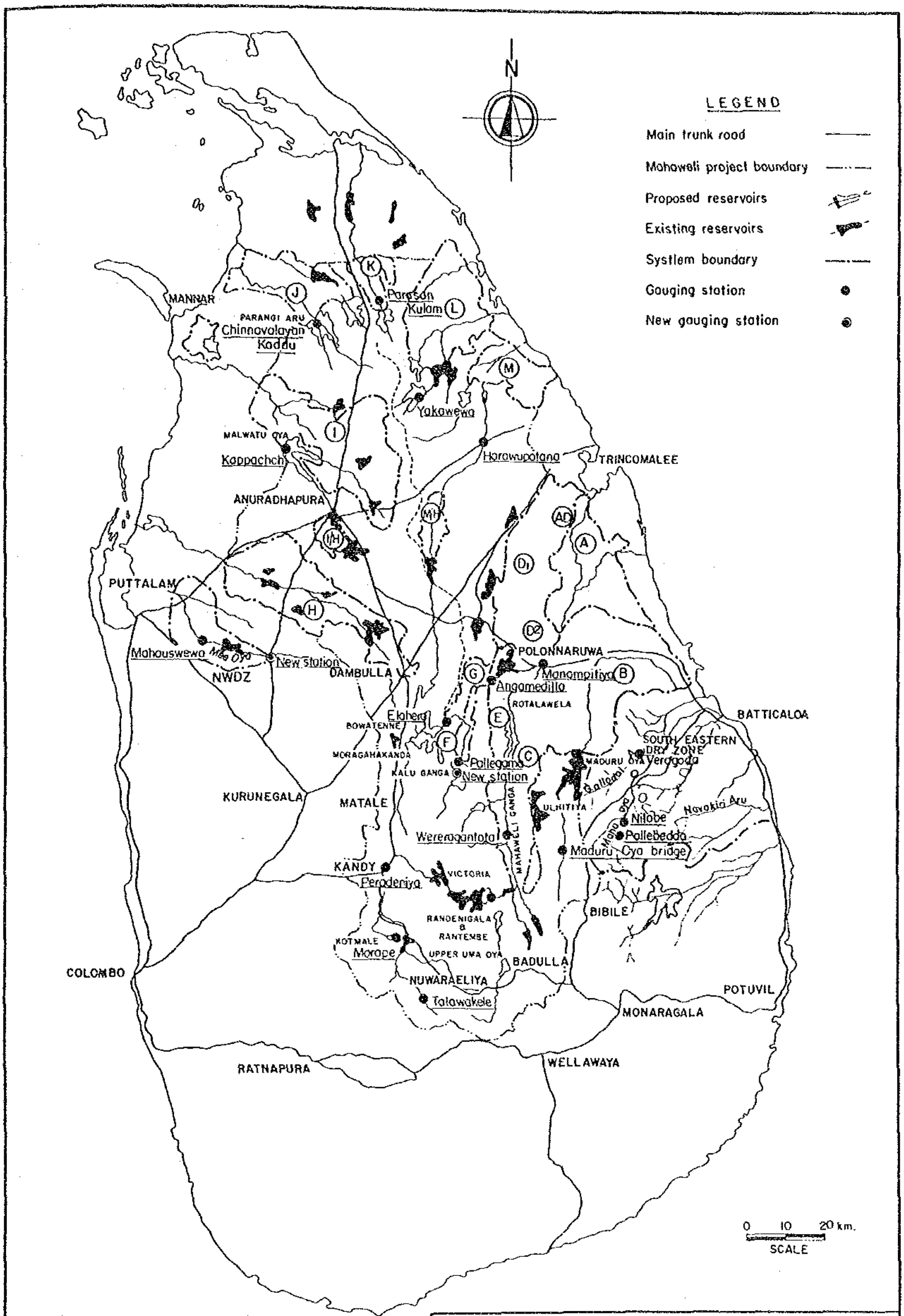

Fig. B.4-1 Location of Hydrological Stations

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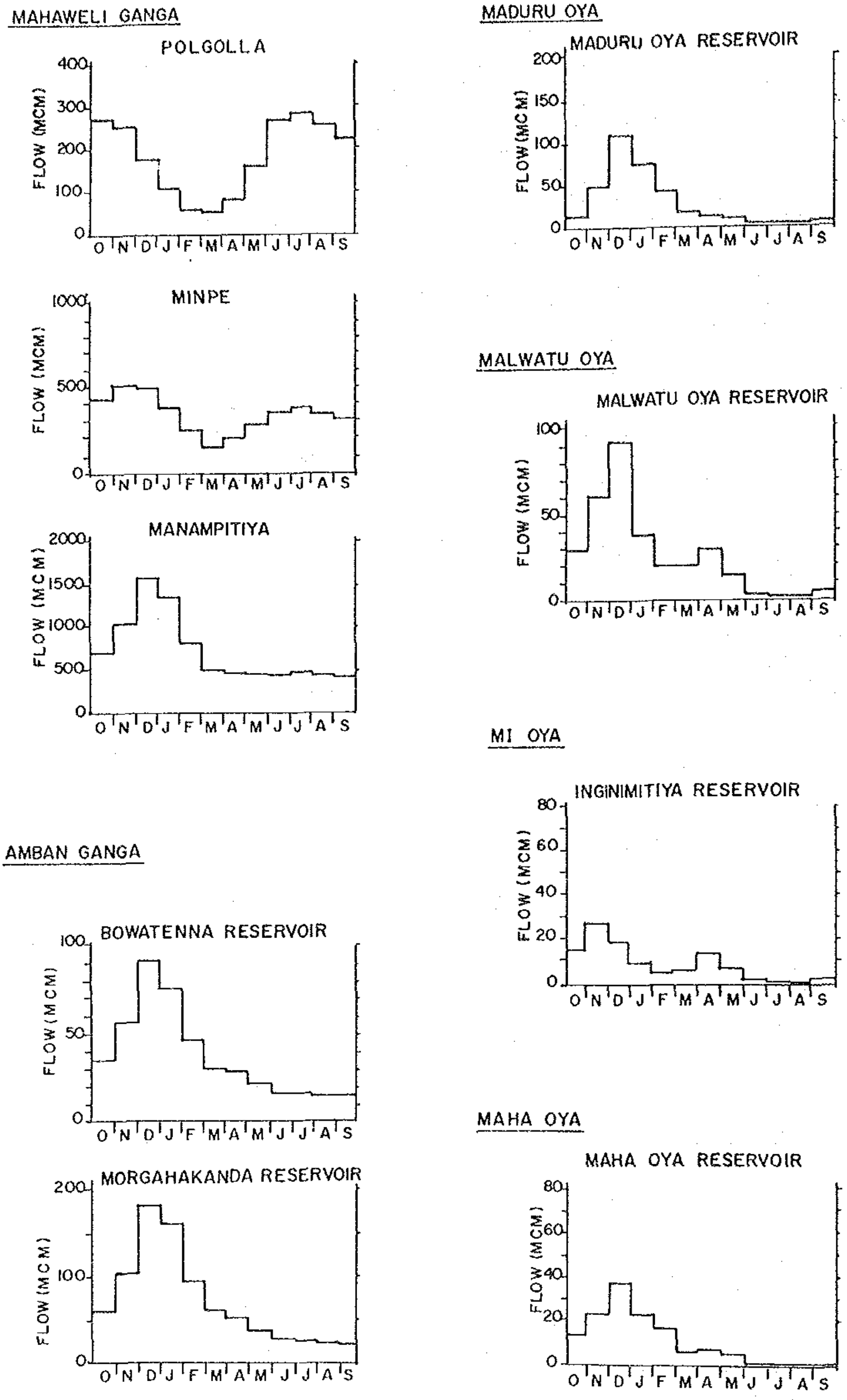

Fig. B.4-2 Average Monthly Flow in the Study Area

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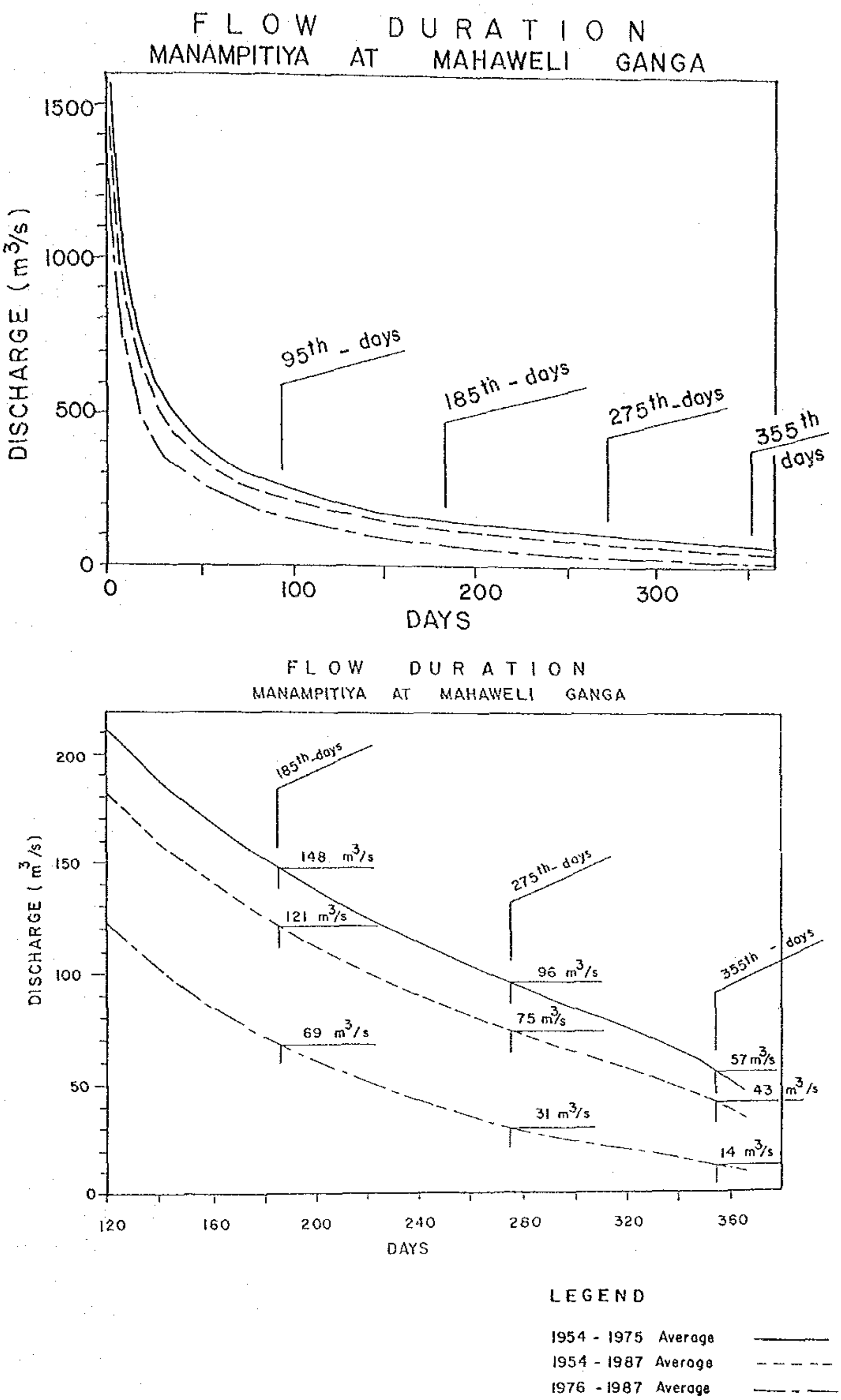

Fig. B.4-3 Flow Duration at Manampitiya

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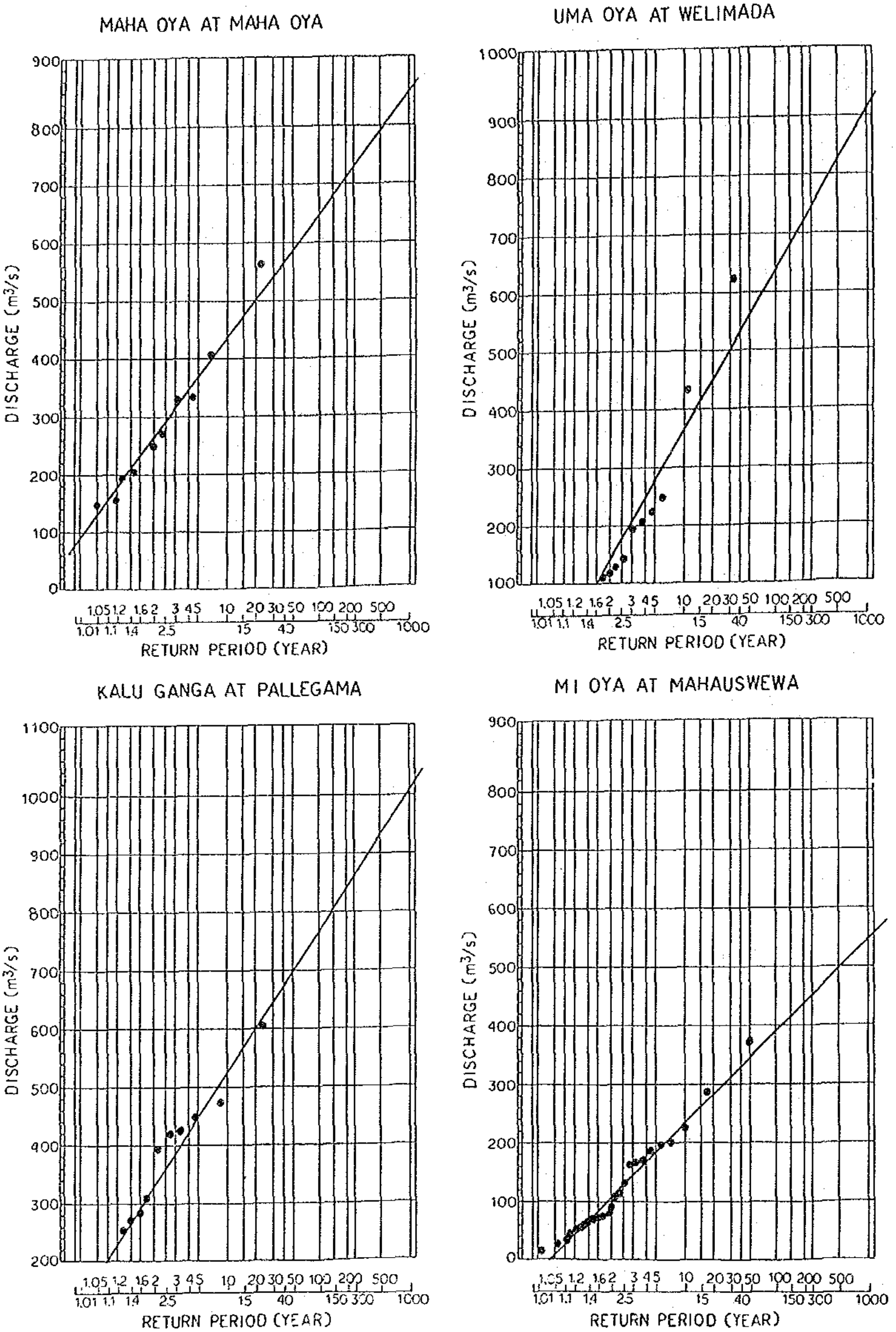

Fig. B.5-1 Probability Plotting of Annual Maximum Flood Records

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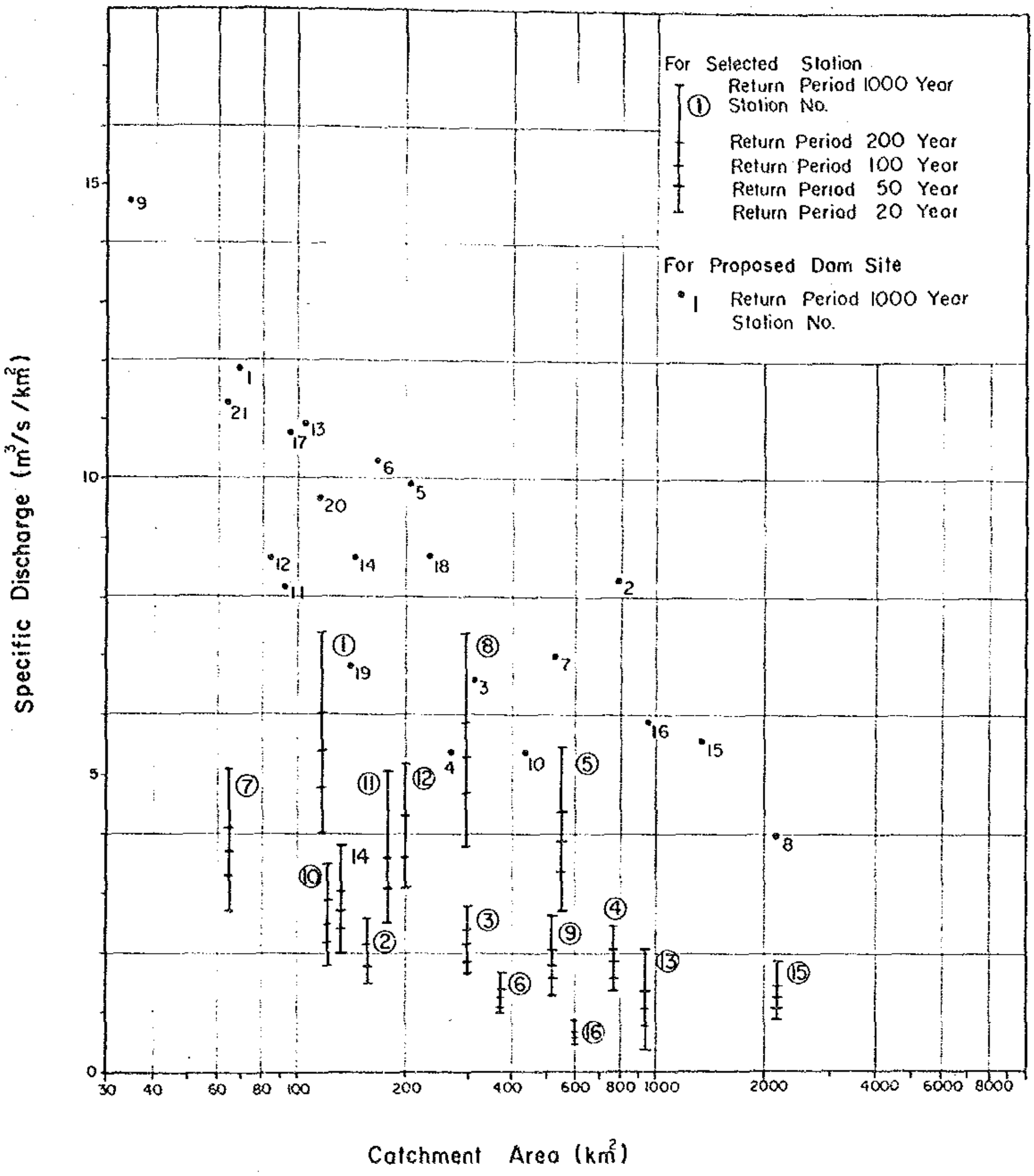

Fig. B.5-2 Specific Flood Discharge-
Catchment Area Plot

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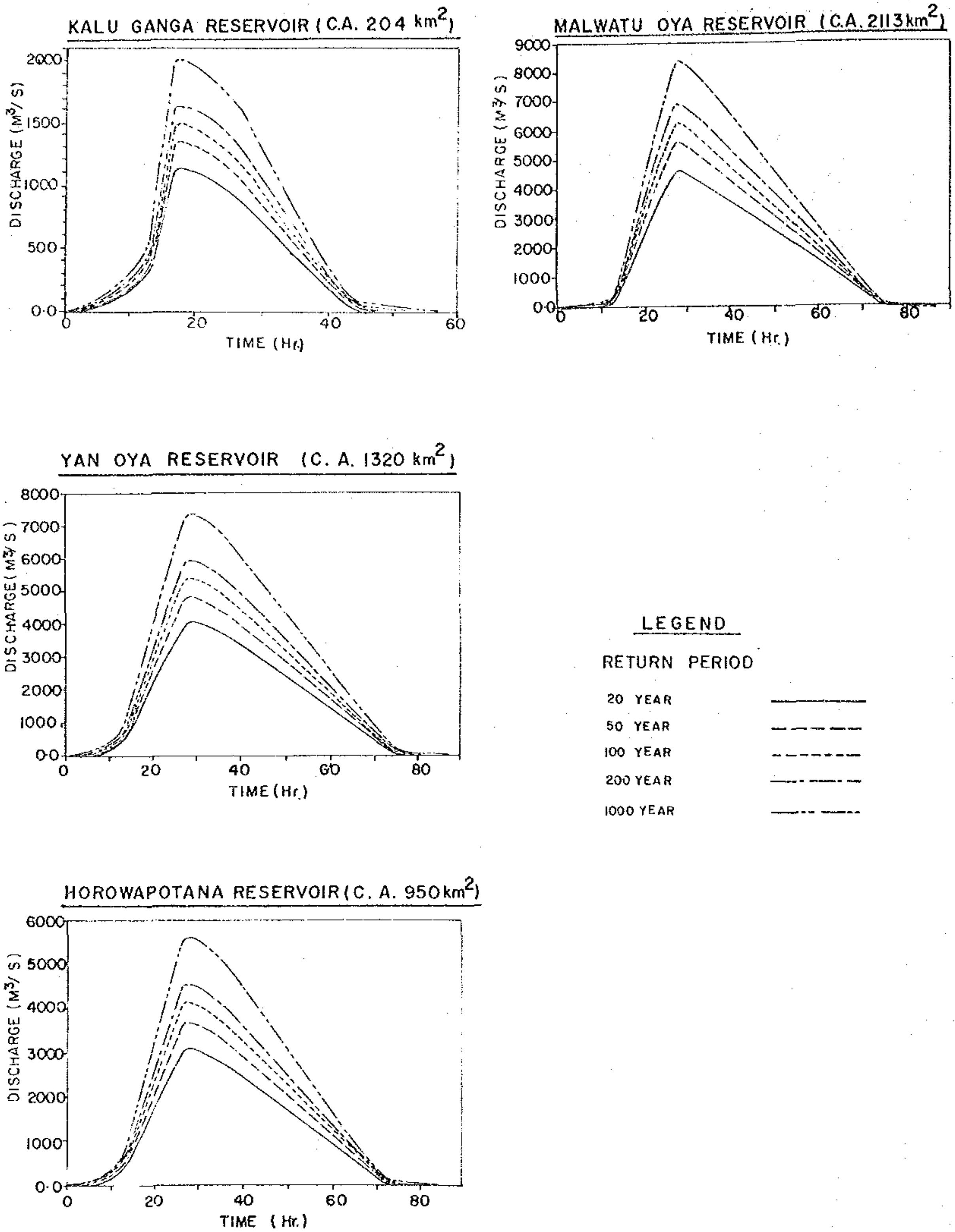

Fig. B.5-3 Flood Hydrograph of Proposed Sites

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ANNEX-C

GEOLOGY

ANNEX - C

GEOLOGY

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ANNEX-C GEOLOGY

C.1 INTRODUCTION

As a part of the Moragahakanda Agricultural Development Project, Phase II (Master Plan), geological investigations were carried out to obtain fundamental data required in planning and designing dams.

Besides the study of geological situations in the study area, the work was focussed upon preliminary assessment of the foundation engineering conditions of geology in the candidate damsites, which had so far been proposed. The investigations for the proposed Kalu Ganga damsite consist of field reconnaissance, core drilling and laboratory tests in conformity to the Scope of Works agreed upon between both government. The study comprises the review of the previous reports and field reconnaissance at the other candidate damsites.

This report presents the results of the above studies and investigations.

C.2 GEOMORPHOLOGY AND GEOLOGY OF SRI LANKA

Sri Lanka is an island country in the Indian Ocean and is located to the southeast of the southern tip of the Indian subcontinent. Stretching 436km in the north-south direction between 6°N and 10°N and 225 km in the east-west direction between 79°E and 82°E, it has a total land area of some 65,500 km^2.

The topography of Sri Lanka is characterized by three types of peneplains of three different levels, i.e. over 1,000 m, 100 m - 1,000 m and lower than 100 m as shown in Fig. C.2-1. The high peneplain corresponds to the Central Highlands surrounding Nuwara Eliya while the middle and low peneplains surround the Central Highlands and gently dip towards the coast respectively.

Most of the rivers originate in the Central Highlands and radially run through the peneplains around the Central Highlands. The longest river is the Mahaweli Ganga which originates in the Central Highlands at EL. 2,500 m and which firstly flows northward, turns east near Kandy (old capital), again north at Minipe and finally flows into the Indian Ocean near Trincomalee on the east coast after crossing the middle and low peneplains. The Mahaweli Ganga has a total length of approximately 330 km and a drainage basin area of some 10,500 km^2.

Almost 90% of the bedrock in Sri Lanka is composed of hard crystalline gneiss, granite or similar rocks subjected to conspicuous metamorphism while the remainder are sedimentary rocks formed in the Mesozoic-Jurassic age, limestone sedimented in the Cenozoic-Tertiary age and Quaternary deposits which are thinly spread over bedrock (Fig. C.2-2).

Although gneiss is dominant in the gneiss rock group which has undergone metamorphism, close examination finds it containing granulite, crystalline schist, migmatite, granite, pegmatite and crystalline limestone. Intrusive rocks consisting of basic rock are found scattered. In terms of the rock facies and geological structures, the rocks in Sri Lanka are classified into three groups, i.e. Highland Series, Southwestern Group and Vijayan Series.

The Highland Series is a product of Pre-Cambrian regional metamorphism under high temperature and pressure, and petrographically divided into a couple of major groups, that is, the Khondalite Group of metamorphosed sedimentary rocks and Charnockites including metamorphosed sediments and metamorphosed basic volcanic rocks. The rocks are frequently folded with the axes trending north to south. The Highland Series develops in a 20 km to 40 km wide belt of north-northeast to south-southwest trend which runs through the center of Sri Lanka covering almost all area of the Hill Country.

The Southwestern Group occupies the southwestern coastal zone which is situated at the southern end of the Highland Series belt, covering up to about 20 km inland from the seashore. The bedrocks of this group are mixture of the gneisses. Quartzite, quartz schist, gneiss and granulite are prevalent in this group.

The Vijayan Series is a complex of gneisses, granites and migmatites which underwent polymetamorphism and was completed through Canbro-Ordovician metamorphism and folding. Developing on both east and west side of the Highland Series belt, the Vijayan Series occupies most parts of the lowest peneplain. Some transitional zones are located on its boundary with the Highland Series, containing rocks characteristic to both series.

C.3 GEOTECHNICAL INVESTIGATION

C.3.1 Contents

Following geotechnical investigations were carried out in Phase II Study:

(1) Kalu Ganga Dam

- Reconnaissance, seismic exploration, core boring, Lugeon tests, test pits and laboratory tests were carried out to obtain conditions of the dam foundation.

- Level materials obtained from both test pits upstream and downstream of the damsite were tested at the laboratory.

- Details of the contents of the geotechnical investigations are given in Tables C.3.1 - C.3.5.

(2) Watawala Dam, Ulapane Dam, Upper Uma Oya Dam (Scheme-1000), Lower Uma Oya Dam (Scheme-500), Wewatenna Dam and Sudu Ganga Dam

- At above mentioned damsites, reconnaissance surveys were carried out.

C.3.2 Investigation Methods

C.3.2.1 Geological Mapping

Geological mapping was conducted for the Kalu Ganga damsite and other sites using topographic maps in a scale of 1:31,680 for the damsite and other sites (Fig. C.3-1).

C.3.2.2 Seismic Exploration

Seismic exploration was conducted on the traverse of some 2.5 km in total length along the axis of the proposed Kalu Ganga dam. Detectors were placed at 5 m intervals to receive the primary seismic waves from explosion point. The data so obtained were arranged in a travel time curve to divide the ground into several wave velocity layers (Fig. C.3-2).

C.3.2.3 Boring Exploration

Prior to the core boring and Lugeon test conducted by the Geological Survey Department (GSD), the technical specifications were discussed and agreed upon by the GSD and JICA Team. The JICA Team was provided with all data obtained in October, 1988 following the completion of the boring and Lugeon test.

The Lugeon test was conducted at 4 drilled holes. Each hole was firstly drilled to a depth of 5 m, a packer was then set at the top of the drilled section and clean water was injected at specified pressure. The volume of injected water at a given constant pressure was measured for 10 minutes at each pressure stage. Following the injection of water at various pressures, the hole was core-drilled by another 5 m for the next water pressure test. The same procedure of drilling and testing was repeated in each hale till the hole reached to the planned depth.

The Lugeon value at each 5 m section was estimated from the injected water volume and the given pressure. All the outcomes of the core drilling are presented in the drilling logs (Fig. C.4-9) attached to this report.

C.3.2.4 Reconnaissance of Borrow Area and Quarry Site

The reconnaissance surveys of the borrow area and quarry site were conducted using topographical map in a scale of 1:31,680 to determine locations where dam embankment materials were able to be obtained. The subject area was within a 5 km radius of the dam site (Fig. C.3-3).

C.3.2.5 Reconnaissance of Damsite

The reconnaissance surveys of the dam site were conducted using topographical maps in scale of 1:2,000 for a total length of 4.8 km along the dam axis for the Kalu Ganga damsite and in a scale of 1:31,680 for other damsites.

C.3.3 Laboratory Tests

C.3.3.1 Sampling

The undisturbed samples were collected from test pits T-2, T-5 and T-7 dug on the dam axis, for soil mechanical tests to determine the nature of the Quaternary deposit in the foundation, while the disturbed samples were collected from all the test pits except the above test pits to determine the suitability of the soil for dam embankment materials.

C.3.3.2 Soil Tests

The following soil tests were conducted to determine the strength of the foundation along the dam axis and the availability of dam embankment material.

(1) Physical Tests

The following physical tests were conducted to determine the physical characteristics of the soils for classification purposes;

Specific gravity, moisture content, gradation, liquid limit, plastic limit and bulk density.

(2) Mechanical Tests

The following mechanical tests were conducted to determine the strength of each soil type, classified through the physical tests;

Proctor compaction, direct shear, unconfined compression, triaxial compression and permeability.

C.3.3.3 Rock Test

The rock compression test of the boring core was conducted at the damsite to determine the bedrock strength. The rocks were charnockite, garnet gneiss and crystalline limestone.

C.3.3.4 Concrete Aggregate Tests

A series of concrete aggregate test, including soundness test and abrasion test, were conducted to determine the suitability of samples collected from the quarry site, for concrete aggregates. The quarry site was selected in the field reconnaissance within a distance of 5 km from the damsite.

C.4 SITE DESCRIPTION

C.4.1 Kalu Ganga Dam

C.4.1.1 Geology of Damsite

The topography around the damsite is in the stage of late maturity in the erosion cycle with old hills which are strongly dissected in the north-south direction. The Kalu Ganga and its tributaries run north in general, and joins the Amban Ganga near Elahera.

The geology of the area is characterized by the Khondalite Group of the Pre-Cambrian Highland Series (quarztite and quartz-schist, crystalline limestone, calc-gneiss and calc-granulite, khondalite and undifferentiated meta-sediments) and charnockites.

Boundaries of some rocks are obscure with gradual transition in the mineral composition, while other rocks show clear boundaries with distinct difference in features along outstanding bedding planes.

A synclinal axis runs in the north-south direction almost at right angle to the dam axis between the T-2 test pit and the No.2 boring site. The geological setting of the site is strongly controlled by the existence of this syncline.

The existence of three faults has so far been assumed by various reports, i.e. a fault running in the east-west direction through a confluence near Pallegama village located upstream of the damsite (suggested by a 1 inch to 1 mile geological map attached to Memoir No.2 Geology of the Country Around Rangala issued by the Department of Mineralogy), a fault running in the east-west direction parallel with and some 500 m upstream of the dam axis, (suggested by the Mahaweli Ganga Irrigation and Hydro-power Survey, Volume VII: 1968) and a fault running in the north south direction at a valley near the T-4 test pit (suggested by the Geologic Structure Map and Section of Kalu Ganga Dam Site: July 1978 by the CECB). The seismic exploration conducted during the present investigation found a low-velocity zone, suggesting the existence of a fault running in the north-south direction.

All strata crop out symmetrically on both sides of the synclinal axis. These gneissose rocks are so hard and massive that they seem to be suitable for dam foundation.

Crystalline limestone (marble) develops in the bottom of the valley on the left side of the river, in the area covering the damsite and downstream.

Core drilling of the crystalline limestone at the hole No.2 indicated frequent intercalations of charnockites. Water leakages occurred in the course of boring, probably because of the partially well developed fissures in the limestone.

In view of the fact that the existence of a spring was confirmed some 1,500 m upstream on the right bank, there is a strong possibility that limestone exists in this area. However, it was not confirmed during the investigation.

Quaternary deposits develop covering the bedrocks. These deposits with thickness of 2 m - 6 m are wide-spread in the valley section of the damsite and are mainly composed of sandy clay, silty sand and gravel (Fig. C.4-1).

C.4.1.2 Exploratory Boring

In order to obtain geotechnical data of the dam foundation, core drilling was carried out at four locations on the dam axis; that is, two locations on the right bank and other two on the left bank as shown in Fig. C.3-3, Fig. C.4-9.

(1) *Boring No.1*

It was drilled of the slope on the left bank located approximately 850 m from Kalu Ganga. The boring depth was 30.07 m. The layer of 0 to 3.0 m depth consists of dark brown sand and clayey soil in which weathered gravel is mixed, while the layer of 3.00 to 13.00 m depth consists of garnet sillimanite graphite gneiss. Of the above, the core sample of 3.00 to 6.80 m depth shows completely weathered rocks, while the core sample of 6.80 to 13.00 m depth shows highly to moderately weathered rocks. The R.Q.D. (Rock Quality Designation) is 0% except for the layer in the depth from 10.0 to 11.50 m which shows the R.Q.D. value of 16%. the Lugeon values are within the range of 13 to 17.

The layer in the depth from 13.00 to 16.20 m consists of garnet granulitic gneiss. Of the above, the core samples of 13.00 to 15.00 m in depth show highly and moderately weathered rocks with the R.Q.D. value of 55%, while the core of 15.00 to 16.20 m in depth fragmental are due to the development of cracks. The R.Q.D. is 0%. The Lugeon value shows 13.

The layer in the depth from 16.20 to 18.45 m depth consists of slightly weathered garnet biotite gneiss. The R.Q.D. is within the range of 59 to 86%. The layer of 18.45 to 30.07 m in depth consists of garnet granulitic gneiss. Of the above, the core samples of 18.45 to 20.10 m in depth shows slightly weathered rocks with the R.Q.D. of 98%, while the core samples of 20.10 to 30.07 m in depth consists of fresh rocks, with the R.Q.D. of 100% and the Lugeon value smaller than 1.

(2) Boring No.2

It was drilled at the flat area located on the left bank, 100 m or so from the Kalu Ganga. The hole depth was 50.18 m. The ground water level was at the elevation of 6.95 m below the ground surface. The surface layer to the depth of 2.12 m consists of reddish brown silty clay while the layer of 2.12 to 4.25 m in depth consists of completely weathered pegmatite.

The layer of 4.25 to 11.93 m in depth consists of gneiss. Of the above, the layer of *4.25 to 5.53 m in depth shows highly to moderately weathered rocks*, with 17% of R.Q.D. and the Lugeon value of 18. The layer in the depth from 8.50 to 11.95 m consists of slightly weathered rocks which bear some cracks. The R.Q.D. is in the range of 40 to 51%, and the Lugeon value is 11.

The layer from 11.93 to 22.07 m in depth consists of crystalline limestones. Of the above, the layer of 11.93 to 20.10 m in depth shows the development of some cracks. Thus, the R.Q.D. falls in the range of 43 to 85%, and the Lugeon values are 11 to 12. The layer of 20.10 to 22.07 m in depth shows slightly weathered rocks with 90% R.Q.D., and the Lugeon value of 8.

The layer of 22.07 to 24.25 m in depth consists of pegmatite. Some cracks are found around the depth of 22.6 m, but fresh hard rocks are generally dominant, showing nearly 100% R.Q.D. The layer of 24.25 to 33.95 m in depth consists of the alteration of strata containing crystalline limestones and charnockite. Some cracks are developed in these strata. The R.Q.D. is in the range of 69 to 98%, while the Lugeon values are 11 to 12.

The layer in the depth of 33.90 to 36.96 m in depth consists of garnet sillinanite graphite gneiss. Of the above, the layer of 33.90 to 35.0 m in depth shows the development of cracks, but the layer of 35.0 to 36.96 m in depth contains fresh rocks. The R.Q.D. is in the range of 69 to 98%, and the Lugeon values are 12 to 7.

The layer in the depth from 36.96 to 40.00 m consists of slightly weathered to fresh garnet biotite gneiss. The R.Q.D. is in the range of 87 to 96%, and the Lugeon value is 7. The layer of 40.00 to 43.14 m in depth consists of garnet granulite with the development of cracks. This stratum has the biotite layer between 42.06 and 42.18 m in depth. The R.Q.D. is in the range of 51 to 84%.

The layer from 43.14 to 50.18 m depth consists of garnet biotite gneiss. Of the above, the layer of 46.30 to 49.38 m in depth contains a great amount of biotite which causes the development of cracks. Thus, the R.Q.D. is 59%. Except for the above, however, fresh rocks are dominant showing 97 to 100% in R.Q.D. The Lugeon value is 8.

(3) Boring No.3

It was drilled on a slope of the right bank, approximately 270 m from the Kalu Ganga. The hole depth was 30.4 m. The ground water level was at the elevation of 11.87 m below the ground surface. The layer of 0 to 5.60 m in depth consists of dark brown and light brown sandy clayey silt. The layer of 5.60 to 5.90 m in depth consists of brownish lateritic soil. The layer of 5.90 to 12.20 m in depth consists of completely weathered rocks, showing sandy soil. The Lugeon value is 18.

The layer of 12.20 to 20.60 m in depth consists of garnet biotite gneiss. Of the above, the layer of 15.20 to 15.40 m in depth shows the development of cracks, but the rest of the layer consists of fresh rocks. The R.Q.D. is in the range of 79 to 100%, and the Lugeon value is 0 in the fresh rock stratum. The layer of 20.60 to 22.35 m consists of fresh calc silicate gneiss rocks, showing the R.Q.D. value of 100% and the Lugeon value of 0.

The layer in the depth from 22.35 to 30.45 m consists of garnet biotite gneiss. Of the above, the layer of 22.35 to 27.70 m in depth consists of fresh rocks, showing the R.Q.D. value of 100% and the Lugeon value of 0. The layer of 27.70 to 30.40 m in depth shows the development of cracks at places. The R.Q.D. value is 41% but the Lugeon value is 1.

(4) Boring No.4

It was drilled at the valley located on the right bank, approximately 600 m from the Kalu Ganga. The boring depth was 37.41 m. The ground water level was at the elevation of 12.36 m.

The layer of 0 to 1.70 m in depth consists of light brown sandy clayey silt, while the layer of 1.70 to 2.15 m in depth consists of yellowish brown lateratic soils. The layer of 2.15 to 2.75 m in depth consists of light brown clayey sand. The layer of 2.75 to 9.60 m in depth consists of garnet granulitic gneiss turned into completely weathered rocks, showing the condition of sandy soils.

The layer of 9.60 to 12.00 m in depth consists of completely weathered rocks, showing the light brown micaceous silt condition. The layer of 12.00 to 13.50 m in depth consists of charnockite showing the sandy gravel condition, with 0% R.Q.D. The layer of 13.53 to 15.77 m in depth consists of garnet sillimanite sandy gravel condition, with 0% R.Q.D.

The layer of 15.77 to 20.00 m in depth consists of garnet charnockite biotite gneiss that would develop a number of cracks. The R.Q.D. is in the range of 0 to 20%. Since the layer of 5.00 to 20.00 m in depth consists of completely to highly weathered rocks, packers could not be set and the Lugeon test could not be carried out.

The layer of 20.00 to 24.00 m in depth consists of garnet biotite gneiss. Of the above, the layer of 20,00 to 23.00 m in depth collapsed down to 4 to 8 cm. The R.Q.D is 10%. The layer of 23.00 to 24.00 m in depth consists of slightly to moderately weathered rocks, showing 46% R.Q.D. value. The Lugeon value is 1.6. The layer of 24.00 to 24.60 m in depth consists of slightly weather garnet granulitic gneiss. The layer of 24.60 to 26.25 m in depth consists of slightly weathered sillimanite gneiss, showing the R.Q.D. value of 52% and the Lugeon value of 1.6.

The layer of 26.25 to 30.00 m in depth consists of garnet biotite gneiss. Of the above, the layer of 28.92 to 28.96 m in depth and that of 29.15 to 29.33 m in depth show a number of cracks. The R.Q.D. values are in the range of 34 to 60%, and the Lugeon value is 10.

The layer of 30.00 to 31.33 m in depth consists garnet sillimanite graphite gneiss, showing 51% R.Q.D. value. The Lugeon value is 1.4. The layer of 33.13 to 37.22 m in depth consists of garnet granulitic gneiss. Of the above, the layer of 33.13 to 32.68 m in depth consists of slightly weathered rocks, thus the R.Q.D. value is 51%. However, the rest of the layer consists of fresh rocks with 100% R.Q.D., and the Lugeon value of 0.

C.4.1.3 Seismic Exploration

The seismic exploration results discerned five velocity layers underlying the Kalu Ganga dam axis.

Interpretation of Velocity Layers

Layer	Velocity (km/sec)	Interpretation
I	Lower than 0.6	Top soil, Talus, River deposits
II	0.6 to 1.2	Completely weathered rocks
III	1.5 to 2.5	Moderately weathered rocks
IV	3.8 to 5.5	Fresh rocks
Low velocities	1.0, 2.0, 2.5	Fracture zone or softened foundation

(1) Velocity layer I (Lower than 0.6 km/sec)

This velocity layer is correlated with top soil, talus and river deposit, with the mean layer thickness of 5 m, except for the hilly area with the thickness of 3.0 m or less.

(2) Velocity layer II (0.6 to 1.2 km/sec)

Correlated with completely weathered rock zone, the boring core samples from this velocity layer is generally crushed into rock fragments and sandy particles. Thickness of the layer is around 5 m on the left bank, while it shows 5 m to 10 m in the bore hole No.3 on the right bank, about 15 m in No.4 and 8 m near the test pit T-3. The sand and gravel deposit, widely covering the flat area on the right bank, falls under this velocity layer.

(3) Velocity Layer III (1.5 to 2.5 km/sec)

Since moderately weathered rocks are the major component of this layer, the boring core samples are for the most part cylindric. The depth of the fresh rock is approximately 5 m on the left bank, while its depth on the right bank is 25 m or more, except in the hilly area.

(4) Velocity layer IV (3.8 to 5.5 km/sec)

Fresh rock is the major component of this layer, and the boring core samples are for the most part cylindric. The depth of the fresh rock is approximately 15 m on the left bank, while its depth on the right bank is 25 m or more, except in the hilly area.

(5) Low Velocity Zone (1.0, 2.0 and 2.5 km/sec)

Existence of continuous soft rock zone or fractured rock zone is conceivable cause of the local low velocities observed. A low velocity zone of 100 m in width detected near the test pit T-4 probably include fractured rock zone or faults of substantial size, because of its so low velocity as 1.0 km/sec. The other low velocity zones, distinguished in the seismic exploration, could represent minor faults or soft rock zone of less significance.

C.4.1.4 Levee Materials Exploration

(1) Quarry

Quarry site (Fig. C.4-2)

The quarry site was selected after reconnaissance of area of about 5 km radius around the damsite. The area thus selected is a small isolated hill located about 1.5 km southwest of the damsite. The bedrock of this hill consists of garnet sillimanite graphite gneiss. Weathering seems thin.

Concrete Aggregate Tests

Rock samples were taken from the hill mentioned above and provided for laboratory test for concrete aggregates. As a result of the tests, it was found that this type of the rocks has a high durability and stability and can be used for concrete aggregates.

(2) Impervious Core Material

Impervious core material site (Fig. C.4-2)

The investigation on the impervious core materials was carried out through laboratory tests on soil samples taken from test pits at ten locations, of which six locations were upstream and four locations were downstream of the damsite. The geological sketches of the test pits are given in Fig. C.4-10. The summary of the laboratory test results are given in Tables C.4.1 to C.4.3.

Upstream site (UT-1 to UT-6)

The slopes located about 2.0 to 3.0 km upstream of the damsite are covered with colluvial deposit and lateritic soils of which thickness ranges from 3.0 to 3.8 m. The deposit intercalates some gravel layer but the majority consists of clayey sand or sandy clay. Thus, it falls under the category of SC according to the Unified Soil Classification System. The soil samples compacted to 95% of γd max. show the mean permeability of 3.6×10^{-6} cm/min, cohesion of 0.45 kg/cm^2, and angle of internal friction ϕ of 17.5°. The deposit can accordingly be used as an impervious core material.

Downstream site (DT-1 to DT-4)

A number of gem pits exist at the downstream of the damsite. Judging from these pits together with the test pits dug newly under the current investigation, the thickness of each materials varies in the range of 2.0 to 11.0 m. The left side of the river channel is covered mainly with sandy clay to clayey sand of 4.0 to 11.0 m in thickness. These soils fall under categories of MH to SC according to the Unified Soil Classification System. The permeability of this soil compacted to 95% of γd max. is 2.76×10^{-6} to 0.55×10^{-6} cm/min and the unconfined compression strength is 1.03 kg/cm^2. It is thus confirmed that the soil can be used for an impervious core material.

C.4.1.5 Geotechnical Evaluation

(1) Foundation of Damsite

The foundation of the damsite is as described below, as judged from the results of the investigations.

a) Quaternary deposit

The deposit covering the ground surface is approximately 6 m thick and unconsolidated. This deposit is not suitable for the foundation of dam structures.

b) Completely weathered rocks

The completely weathered rock zone underlying the superficial Quaternary deposit corresponds with a seismic wave velocity layer of 0.6 to 1.2 km/sec and a section of 10 Lugeon or more in permeability. The thickness varies from 5 to 20 m. Core recovery in drilling this zone is too poor to give any decisive evaluation of completely weathered rock, while it seems highly probable that this sort of rock may be usable for foundation for shell zone of a fill dam, though not for foundation of impervious core zone. It will be a point of the future investigation to clarify the geotechnical condition of this zone by means of core drilling with more suitable equipment and technique.

c) Moderately weathered rocks

The moderately weathered rock is deemed to correlate with the seismic wave velocity layer of 1.5 to 2.5 km/sec and the zone of permeability from 4 to 13 Lugeon with average core recovery and R.Q.D. around 50%. Cracks are developed in general. Although the moderately weathered rocks may be competent for foundation of the impervious core zone of a fill dam of small to medium height, if grouting is effective in it, it is recommendable for a high dam to sink the impervious core to the surface of a slightly weathered rock, which will be encountered at the depth of 12 to 15 m from the natural ground surface, according to the boring No.1 to No.3.

d) Fresh Rocks

The bedrock of this category is sufficiently good for dam foundation in its strength and watertightness, even if it bears some minor fissures. It lies, however, often so deep under the ground surface that it may not be practical to excavate the dam foundation to the level of the fresh rock.

(2) Impervious core materials

Earth material for the impervious core zone that is available in this site falls under SC and MH in the Unified Soil Classification System. The SC and MH layers are about 3.0 m thick upstream of the damsite and 4.0 to 11.0 m thick downstream. In terms of geological structure, the distribution of limestones is possible in the upstream area, and stripping of the earth material may accordingly cause some problem of water leakage.

The limestone develops also downstream of the damsite. Careful approach is required in taking the earth core material. It is recommended to limit the borrow area outside the extent of the limestone development, e.g. the foot of hills on the left bank downstream of the damsite.

(3) Rock Material

A small hill located about 1.5 km upstream of the damsite was selected for the rock material quarry. It consists of garnet sillimanite graphite gneiss, and the rock quality is high, with the estimated strength of about 1,000 kg/cm^2. The location is also favorable for hauling rock materials.

(4) Concrete aggregate material

For the lack of any substantial deposit of sand and gravel within a reasonable distance from the damsite, concrete aggregates will have to be produced by crushing the quarry rock. The garnet sillimanite graphite gneiss is deemed suitable for this use in its quality and quantity. Results of the aggregate test are presented in Table C.4.5.

(5) Filter material

The filter material should also be produced by processing the quarry rock, because of poor development of natural sand deposits as found in the field reconnaissance to date.

C.4.2 Watawala Dam

Bedrock of the Watawala damsite on the upper Mahaweli Ganga is again rocks of the Khondalite Group and charnockites. With an anticlinal axis running off the left wing of the damsite parallel to the valley, the bedding shows a monoclinic setting with the strike nearly similar to the river direction and the dip of about 45 degrees from the left bank toward the right bank, or N20°W/40° to 50°NE. The dip of the bedding plane may be unfavorable for stability of slope on the left bank (Fig. C.4-3).

C.4.3 Ulapane Dam

The Ulapane damsite on the upper Mahaweli Ganga is also situated in the geological province of the Pre-Cambrian Highland Series with khondalites and charnockites. This area seems technically less disturbed and more stable than other sites. No serious problem is envisaged from foundation engineering point of view (Fig. C.4-4).

C.4.4 Upper Uma Oya Dam (Scheme 1000)

The same kind of bedrock as in the Lower Uma Oya site will be the foundation rock for the Upper Uma Oya dam, which will be located at another site on the Uma Oya river, a tributary of the Mahaweli Ganga. Some limestone beds are also located on the left bank. Charnockite outcrops on the river bed show the strike/dip of N30°W/40°SW. A fault with southwest-northeast trend probably runs on the left bank of the damsite (Fig. C.4-5).

C.4.5 Lower Uma Oya Dam (Scheme 500)

The geological condition of the Lower Uma Oya damsite on a tributary of the Mahaweli Ganga, is characterized by rocks of the Khondalite Group and charnockite gneiss the Pre-Cambrian Highland Series. The charnockite crops out on the river bed. With a synclinal axis running nearly along the Uma Oya river, the rock beds on both banks appear to dip toward the river, resulting in minor slips on the slopes and formation of talus deposits at their feet. Stability of the abutment slopes would be a point of foundation engineering question for this damsite (Fig. C.4-6).

C.4.6 Wewatenna Dam

The bedrock of the Wewatenna damsite on the Badulu Oya river, which is a tributary of the Mahaweli Ganga, consists of Khondalite Group rocks and charnockite gneisses of the Pre-Cambrian Highland Series. Outcrops of charnockites are observed on the river bed. The strike of the strata is similar to that of the river direction, i.e., south-north strike, which curves toward east by 30 to 40 degrees.

While there is possibility of limestone distribution in the Khondalite Group rocks, it could not be confirmed by the current investigations. No serious problem is envisaged so far since hard gneiss rocks would become the foundation of the dam (Fig. C.4-7).

C.4.7 Sudu Ganga Dam

The bedrock of Sudu Ganga damsite located at the upper reaches of Amban Ganga belongs to the Highland Series of Pre-Cambrian. Charnockite distributes on the right bank of the river, while limestone is found developing in the middle to upper levels of the slope on the left bank. The limestone bed shows from south to north strikes, parallel with the river course.

The charnockites in this area is very hard and suitable for dam foundation.

The limestone, that might cause large water leakage problem through solution cavities, lies in levels higher than the contemplated reservoir level and accordingly will not be harmful. It should be noted that if any alternative height for this dam is considered, the level of the limestone bed should be an important factor to control the dam height to be planned (Fig. C.4-8).